Assessing Team Performance in the Operating Room: Development and Use of a "Black-Box" Recorder and Other Tools for the Intraoperative Environment

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BACKGROUND: The objective of this research was to develop a digital system to archive the complete operative environment along with the assessment tools for analysis of this data, allowing prospective studies of operative performance, intraoperative errors, team performance, and communication. Ability to study this environment will yield new insights, allowing design of systems to avoid preventable errors that contribute to perioperative complications.

STUDY DESIGN: A multitrack, synchronized, digital audio-visual recording system (RATE tool) was developed to monitor intraoperative performance, including software to synchronize data and allow assignment of independent observational scores. Cases were scored for technical performance, participants' situational awareness (knowledge of critical information), and their comfort and satisfaction with the conduct of the procedure.

RESULTS: Laparoscopic cholecystectomy (n = 10) was studied. Technical performance of the RATE tool was excellent. The RATE tool allowed real time, multitrack data collection of all aspects of the operative environment, while permitting digital recording of the objective assessment data in a time synchronized and annotated fashion during the procedure. The mean technical performance score was 73% ± 28% of maximum (perfect) performance. Situational awareness varied widely among team members, with the attending surgeon typically the only team member having comprehensive knowledge of critical case information.

CONCLUSIONS: The RATE tool allows prospective analysis of performance measures such as technical judgments, team performance, and communication patterns, offers the opportunity to conduct prospective intraoperative studies of human performance, and allows for postoperative discussion, review, and teaching. This study also suggests that gaps in situational awareness might be an underappreciated source of operative adverse events. Future uses of this system will aid teaching, failure or adverse event analysis, and intervention research. (J Am Coll Surg 2005; 200:29–37. © 2005 by the American College of Surgeons)

The operating room is a high-risk environment, yet the factors contributing to medical errors within this context remain poorly understood. Methods for prospective analysis and retrospective review of human performance within the operative setting are needed to develop strategies that address the risks inherent in this environment. Communication and team coordination are particularly crucial in dynamic environments such as the operating room. Although communication patterns and behaviors have been studied in other clinical settings through self-report logs,[1] observation,[2] and ethnographic methods,[3] there is a paucity of research focusing on the team environment within the operating room.[4] This is notable given a recent estimate that many deaths each year result from medical errors,[5] most of which occur in the peri-

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Abbreviations and Acronyms

FIT = flexible interface technique
LC = laparoscopic cholecystectomy
RATE = Remote Analysis of Team Environments

operative setting. Estimates suggest that potentially avoidable complications occur in up to 40% of surgical admissions. Finally, complications associated with mortality in surgical patients frequently occur in the operating room.[6]

The ability to record and review events in the operating room, similar to aviation's use of a black-box recorder, can be useful for studying team behavior, the effectiveness of various interventions, or the usability of newly acquired equipment, all leading to insights into human performance in this high-risk setting. Such capability is appealing in regard to case review by surgical teams for use in teaching and performance reviews. Our goal was to develop a customizable digital recording and analysis system for the purpose of studying human performance in the operative environment. This article describes the methods developed to record and review a pilot series of laparoscopic cholecystectomy (LC) cases, score the technical proficiency of the operating surgeons based on an established scoring tool, and record key operative events and communication patterns. We report the results of a postcase assessment done immediately after the operation to measure team members' situational awareness and their perceptions of case difficulty, comfort during the case, and satisfaction with the surgical outcomes, efficiency, and communication of the surgical team. The methodologic, technical, social, and legal challenges associated with development and use of such systems have been detailed previously.[7]

METHODS

The Remote Analysis of Team Environments (RATE) tool, a digital audiovisual data collection and analysis system, automates the ability to digitally record, score, annotate, and analyze team performance. Because the system is mobile, data can be collected from different operating rooms using a single system.

RATE hardware architecture

Four high-end personal computers with video capture cards are used for data collection (Fig. 1). The computers are used to record four separate video and eight separate audio tracks; one video feed and two audio feeds are encoded into each computer. The four videos are comprised of a room camera (with the circulating nurse's voice), an overhead camera (with the scrub technician's and camera operator's voices), a view of the physiologic data (with the attending anesthesiologist's and resident's voices), and the intracorporeal laparoscopic image (with the attending surgeon's and resident's voices). The purpose of recording each individual's voice in a separate audio track is to make listening and transcription easier by being able to select certain voices during replay. The computers are able to process, store, and broadcast the data, while any personal computer connected to the local area network can view all of the data in a synchronized fashion using the RATE software.

RATE software

The RATE software is written in Microsoft Visual Basic for the Windows platform. The software allows for:

- Digital recording of multiple video feeds (colocated or distributed), with up to two audio feeds for each video feed
- Watching up to four synchronized videos and eight audio streams simultaneously
- Selectively muting or enabling each pair of audio feeds and selectively hiding or showing each video feed
- Counting and scoring team communication patterns and technical proficiency
- Tracking events
- Annotating or transcribing segments of video

All data are annotated with a time code and categorized. Unlike similar programs using analogue video by controlling a video cassette recorder, eg, MacShapa,[8] RATE directly accesses the streamed or stored digital video source and runs on the Windows platform. One advantage of using digital video involves the capacity to skip from segment to segment in a fraction of the time it takes to navigate analogue video. Any time-stamped event can be "double clicked" and, within seconds, the synchronized audio and video data will play from that point. A second advantage of digital data is that the audio and video streams can be isolated from each other for easier analysis. Finally, the RATE system enables synchronization of multiple audio and video feeds with event data for team analysis purposes.

To understand the general communication patterns in the operating room and develop the methodology for

Figure 1. The Remote Analysis of Team Environments (RATE) tool, a digital audiovisual data collection and analysis system. The tool allows trained individuals to annotate and transcribe case segments, record verbal call-outs and conversation by team members, time-stamp particular episodes for easy review, and score technical proficiency of the surgeon(s). Such a tool can be used by researchers for team performance analysis in the high-risk operating room environment or by surgical team members for case review, education, and discussion. Trained observer(s) mark: events, communications, and technical errors. The tool can be used for transcription, scoring, accident investigation, certification, team training, and debriefing. All data are compressed, saved, synchronized, selectable, indexable, and protected.

recording them using the RATE software, utterance counts were captured with the FIT-System (flexible interface technique)[9] created for recording observational data (Fig. 2). The components of the system include a Palm-Pilot with a touch screen and a FIT-template overlay. This methodology allowed us to determine communication density and direction among participants in the operating room. Personnel roles were mapped on the template based on standard positions around the operating room table to facilitate information recording. The FIT software was programmed to capture marks made in each identified area, using a tap in the correct region for each statement or utterance from individuals in the room. Events and quotes also were transcribed verbatim to categorize conversation themes and patterns during the case. This information was then used as a framework

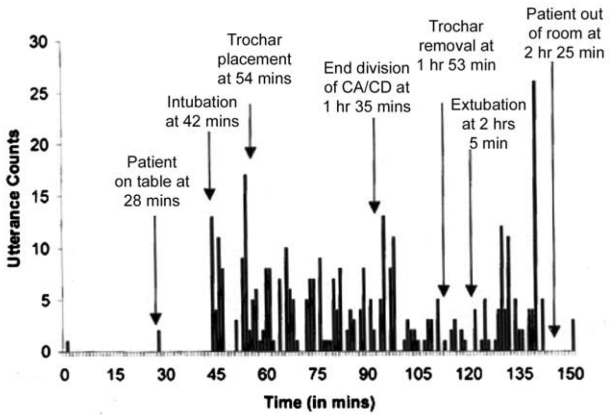

Figure 2. Utterance counts during an elective laparoscopic cholecystectomy procedure. CA, cystic artery; CD, cystic duct.

to incorporate the recording and marking of communication patterns with the RATE software.

Setting

LC was chosen as the model procedure because it is the most frequently performed general surgical operation at our institution, its conduct is fairly routinized, technical performance is fairly consistent from surgeon to surgeon, and case length is sufficient for study, but not excessively long to preclude data analysis. In addition, a well-described scoring system has been developed to assess technical performance of the procedure. During enrollment, adult patients undergoing elective LC were screened for eligibility. This pilot study targeted an enrollment of 10 sequential procedures. This study was reviewed and approved by the University of Virginia Human Investigation Committee. Informed consent was obtained from all participants including patients, physicians, students, and staff participants.

Scoring

Each surgeon's technical skills were assessed using the LC scoring tool developed by Eubanks and colleagues.[10] This tool awards points for the proper performance of each of a series of 23 specific steps during LC. Accumulation of 100 points is possible if a cholangiogram is completed, 80 points if not. Error points are then deducted for any of 21 technical mistakes that might occur during LC. The final score, reported as a percentage of the total possible score, is a relative measure of technical skill, with demonstrated reliability and validity as an assessment tool of the technical skills required for LC. Two trained observers scored all parts of the cases. Any discrepancies in scoring were reviewed and agreed upon.

Situational awareness was assessed for all team members (surgeons, anesthesiologists, residents, students, and nurses) immediately at the end of each case. This structured, 24-item tool (Fig. 3) was developed by a team of laparoscopic experts to assess: demographic information about the respondents; their knowledge in regard to specific key elements of the patient's case necessary to prevent complications (eg, perioperative antibiotics, sequential compression devices and so forth) or required for operative decision making (eg, the need for a cholangiogram); and the details of the procedure (eg, appropriate clip placement, observation for hemostasis) just performed to ensure appropriate completion of procedure goals. Participants also assessed their comfort with the overall conduct of the procedure (was it going well or not?), its perceived technical difficulty, their satisfaction with the final outcomes for the patient, the functioning of the operating room team, and their perceptions of the study itself. The situational assessment questions were designed to be verifiable by reviewing either the patient record or the recorded data in the RATE tool. An advanced practice nurse with extensive surgical, critical care, and operating room experience verified these data. Situational awareness scores (items 1 to 15), were computed for each team member using a master sheet of responses from the assessment tool. A value of 1 was given for each correct response; a value of 0 for each incorrect response or one marked "not sure." Items left blank were judged "not sure." The final part of the tool, about participant self assessment, was evaluated using a five-point Likert scale: Mean scores + SE of the mean are reported.

RESULTS

Ten sequential LC cases were enrolled. Nine completed the study and one was ineligible for a technical score because it was converted to an open procedure. Case demographics and error counts are shown in Tables 1 and 2. No cholangiograms were indicated, so the maximum Eubank's score was 80 for all cases. The mean technical score for the nine laparoscopic cases was 58.3 ± 22.3, or 72.9% ± 27.9% of the maximum. Prolonged operative time (more than 90 minutes) was common in cases with lower scores. Our results are similar to those reported by Eubanks and associates,[10] with liver injury (no bleeding) and unintentional release of the gallbladder as the most common errors identified. The incidence of errors increased as operative time increased.

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Laparoscopic Cholecystectomy Post-Procedure Assessment

Service: (circle one) Anesthesia Surgery Nursing OR Staff Traveler / visitor
Role: (circle one) Resident Chief Attending Circulator Scrub CRNA Student

Amount of time in current role?________

Present for: (circle all that apply) All of case Beginning of case Middle (relief) End of case Intermittently 'Critical Portion'

Gender M F Days since last lap chole'y_____ Hours of sleep in last 24 hours_____

Total number of lap cholecystectomies ever performed / participated in______

FROM MEMORY: (Please do not refer to the chart or ask others)

1) What comorbidities / PMHx did this patient have? (circle all that apply)

Neuro-psych disease CAD COPD Diabetes Cancer Weight loss

Jaundice Fevers Past Abdominal Surgery Renal Insufficiency Penicillin Allergy Autoimmune

Hepatitis Cirrhosis Bleeding /Clotting Abnormality Other: Not Sure

2) Please record what you know with regard to this patient's pre-operative laboratory studies:

AST/ALT	**Low**	**Normal**	**High Normal**	**High**	**Not Sure**
$Bili_T$	**Low**	**Normal**	**High Normal**	**High**	**Not Sure**
$Bili_{indirect}$	**Low**	**Normal**	**High Normal**	**High**	**Not Sure**
Alk Phos	**Low**	**Normal**	**High Normal**	**High**	**Not Sure**

3) What was this patient's preoperative CBD diameter (by U/S)? **Normal Dilated ___mm Not sure**

4) Were there stones in the gall bladder in the preoperative ultrasound? **Yes No Not sure**

5) Was an intraoperative cholangiogram or ultrasound indicated? **Yes No Not Sure**
Why (or why not)?____________________

6) What appliances did your patient have in place prior to the skin incision? (circle all that apply)
OG / NG tube Foley Catheter SCD's Not sure

7) Did your patient receive any antibiotic prophylaxis? **Yes No Not sure**

8) If you answered yes to the above question, what antibiotic (and what dose) did your patient receive?
Antibiotic:__________ Dose:__________ Was it re-dosed during the case? **Yes No Not sure**

9) Were the port sites injected with local? **Yes No Not sure** At what point(s) in the case?

10) Was there any pathology visible in the pelvis, or anywhere else in the abdomen other than the gall bladder (e.g. from unrelated disease processes or unintended injuries from trochar placement)? If yes, please describe:____________________

11) Was the cystic artery well identified prior to use of the clip applier? **Yes No Not sure**
If not, why?____________________

12) Was the cystic duct well identified prior to use of the clip applier? **Yes No Not sure**
If not, why? ____________________

13) How many clips (proximal and distal) were placed on the cystic artery? _____ cystic duct?_____

14) Was clip placement on the cystic artery and duct(s) re-checked prior to closure? **Yes No Not sure**

15) Was gall bladder bed hemostasis re-checked prior to closure? **Yes No Not sure**

16) Did any adverse events, "near-misses", or errors occur during this case? **Yes No Not sure**

17) If you answered "Yes" to question 16, please explain: ____________________

18) Please rate the difficulty of this case: **1 2 3 4 5**
Easy Somewhat difficult Hard

19) Please rate your comfort during this case: **1 2 3 4 5**
At ease Somewhat comfortable Uncomfortable

Figure 3. Situational awareness tool.

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20) How satisfied were you with:

a. The Surgical Outcome? 1 (Very satisfied) 2 3 (Somewhat satisfied) 4 5 (Not at all satisfied)

b. The Efficiency of the Surgical Team? 1 (Very satisfied) 2 3 (Somewhat satisfied) 4 5 (Not at all satisfied)

c. The Communication of the Surgical Team? 1 (Very satisfied) 2 3 (Somewhat satisfied) 4 5 (Not at all satisfied)

21) How do you feel about participating in similar (video research) cases in the future?

1 (Look forward to it) 2 3 (Neutral) 4 5 (I dread it)

22) How many times previously have you filled out a questionnaire for this research protocol? _____

23) Amount of time that passed between case completion and completion of this survey: ______ hours

24) Other Comments:

Figure 3. Continued

The FIT-System worked well as designed, allowing easy recording of "utterance counts" (who spoke when), as illustrated in Figure 2. This figure also illustrates the large quantity and density of communication in the operating room, which could not be analyzed in detail with the FIT-System. So, we have abandoned the FIT system and expanded our RATE software to allow detailed assessment of verbal communication in the operating room. This new menu-driven system allows selection of team members initiating conversation along with the person they are speaking to, followed by recording of the type and content of the communication. Examples include "Surgeon-Resident: Teaching-Anatomy" and "Surgeon-Nurse: Requesting-Tools." These data are accurately time stamped and synchronized, facilitating parallel review with the audio-video data. Finally, data from the individual audio components are sufficiently clear to allow transcription of selected, or all, quotes from an individual case. So, the RATE tool provides a robust system allowing analysis of verbal communication patterns and content.

Table 1. Case Demographics (n = 10)

Characteristic	Data
Length of case (skin incision to skin closure), min	94.7 ± 26.9
Discharge status	
Same day	7 (70%)
Next day	2 (20%)
Readmission status	
Not readmitted	9 (90%)
Readmission not related to operation within 30 d	1 (10%)
Eubanks score* (mean ± SD)	58.3 ± 22.3

*Total possible score of 80 for all cases.

Sixty-eight situational awareness tools were completed during the study. Total individual case participants included 6 attending surgeons, 6 attending anesthesiologists, 13 residents, 14 nurses, and 4 medical students. Some individuals participated in more than one case. Situational awareness is presented as a percentage score of correct responses for clinical items (questions 1 to 15); a composite score was calculated for each team role and is presented in Figure 4. Subjective question (items 18 to 21) responses were not included in this score. The data demonstrate that the attending surgeon was the primary holder of critical patient and case information. There was a considerable lack of situation awareness in many other team members. Review of the RATE data demonstrated that no preprocedural briefing to review critical case information or the expected conduct of the procedure was observed in any of the cases. Likewise, no postprocedure performance review was conducted after any of the observed cases, as documented by RATE.

Participants also rated case difficulty, individual comfort during the case (eg, unease about the conduct or specific aspects of the case), satisfaction with the surgical outcomes and efficiency and communication of the surgical team (Fig. 3). Of the 68 completed tools, 2 were not used because there were partial or no responses to these questions. Participants' case evaluations are shown in Figure 5. The case difficulty level was relatively easy, with group mean scores ranging from 1.17 to 2.60. Attending surgeons reported slightly higher, but not major, case difficulty than the average score. Case difficulty rated by attending surgeons in-

Table 2. Error Counts (n = 9 Laparoscopic Cases)

Errors	Total n	Average per case
Gall bladder		
Gall bladder injury (no bile spilled)	7	0.78
Unintentional release of gall bladder	18	2.00
Gall bladder injury (bile spilled)	1	0.11
Liver		
Liver injury (no bleeding)	23	2.56
Liver injury (bleeding)	3	0.33
Major vascular injury	0	0.00
Common bile duct, hepatic duct injury	0	0.00
Cystic duct		
Additional attempt at clip placement on duct	3	0.33
Additional attempt at ductotomy	NA	NA
Additional attempt at cystic duct cannulation	NA	NA
Misplaced clip on cystic duct	2	0.22
Unintentional removal of cholangiogram catheter	NA	NA
Unintentional cystic duct transection	NA	NA
Failure to cannulate patent cystic duct	NA	NA
Cystic artery		
Additional attempt at clip placement on artery	6	0.67
Additional attempt at cutting cystic artery	2	0.22
Misplaced clip on cystic artery	0	0.00
Mistaking artery for duct	0	0.00
Cystic artery tear	1	0.11
Miscellaneous		
Other abdominal injury	0	0.00
Prolonged operative time (> 90 min, excluding cholangiogram)	5	0.56

NA, not applicable.

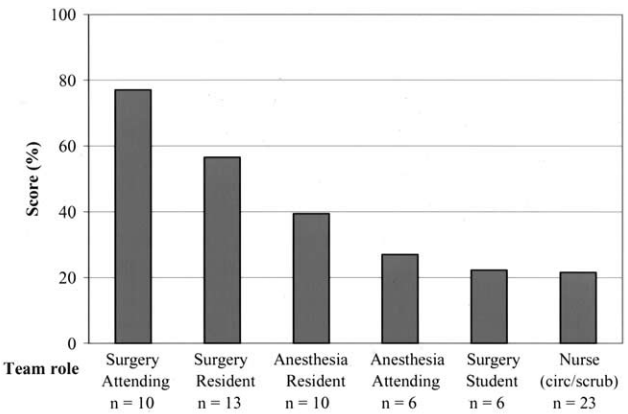

Figure 4. Situational awareness scores evaluating participant's knowledge of critical patient information and case events (questions 1 to 15 from Fig. 3); n = number of scored tools for each category. The "Anesthesia Resident" category includes both anesthesiology residents and nurse anesthetists. The "Nurse" category includes circulating and scrub nurses. Of note, many of the nurses reported their presence intermittently for a given case.

creased with increased case length. Comfort with overall conduct of the operation was good, with similar scores from all groups of participants. Likewise, all participants were similarly satisfied with the surgical outcomes. Finally, team efficiency and communication were deemed good, with no notable differences among cases or team roles. Although attending surgeons tended to mark lower team efficiency and communication scores for some cases, there were no major differences among other team members.

DISCUSSION

Although the operating room is a common site for medical errors, systematic assessments of intraoperative performance have not been undertaken and little research into these errors and interventions to prevent them exists. Because the operating room is an extremely data-dense environment, pertinent information about what occurs during an operation often goes unrecorded, making retrospective studies of intraoperative events difficult and uninformative.[6] Consequently, new methods are needed to capture the rich and complex data surrounding the care of a patient in the operating room. Only through analysis of this complex data will progress be made toward identifying and understanding the human behaviors that occur in the operating room and their relationship to errors. Additional benefits of these analyses include improved communication, teamwork, and efficiency in the operating room.

This report details the design and use of a new tool constructed to overcome the lack of methods to capture this complex data. Presented is evidence of the usefulness and flexibility of this multimedia data recorder known as the RATE tool, demonstrated in a pilot study of LCs. With this digital recording system, a temporary or permanent record of operative events can be created for study, review, and teaching purposes. The RATE tool allows for analysis of individual data sets or integrated data from simultaneously recorded sources. The ability to synchronize and date and time stamp the data allows nearly instantaneous review of single or multiple data points in an efficient manner, unlike the more difficult to access data stored on analogue video (VHS). This

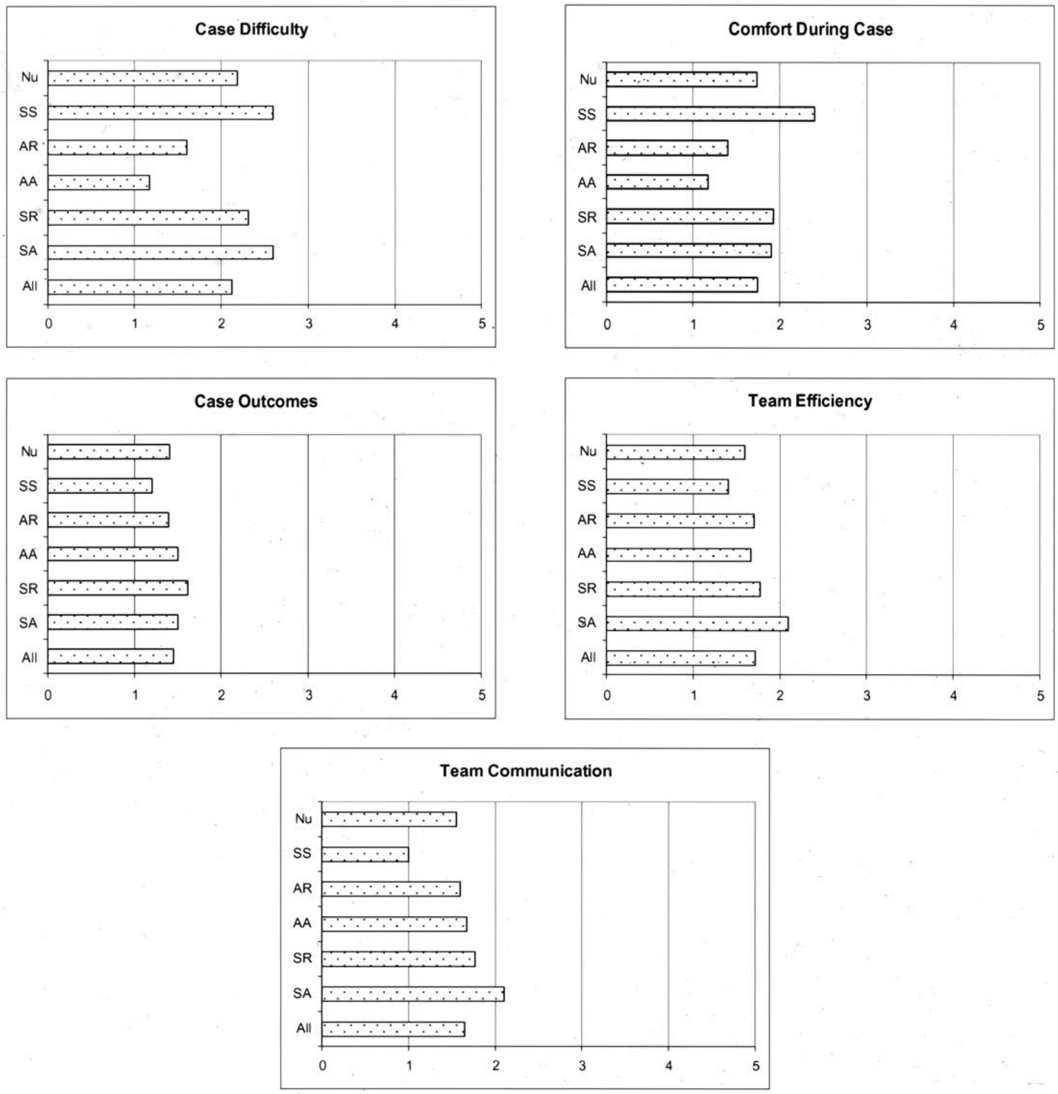

Figure 5. Case evaluation scores. Each case was scored by participants based on items 18 to 20 as shown in Figure 3. Mean scores for each item were generated for the groups as listed: Nu, nurses; SS, surgical student; AR, anesthesiology resident; AA, anesthesiology attending; SR, surgical resident; SA, surgical attending; and All, the average score for all participants. No considerable differences were noted between any of the groups.

allows rapid review of a typical 60- to 90-minute LC in a few minutes, a fraction of the time required for a similar review of analogue data. Individual or collective data points can be efficiently reviewed at any of these time points, unlike analogue data which cannot be easily separated into individual data streams. In addition, real-time intraoperative metrics can be collected including: time to set up and perform certain procedures; technical proficiency and strategies of the operating surgeon(s); the utility of the tools (intraoperative devices) used; and team coordination and communication patterns. This allows performance review of individuals or the team. These data can be analyzed by researchers or reviewed by members of the operating team, particularly during cases involving errors or unexpected events.

In this pilot, technical proficiency as scored by Eubanks and colleagues[10] was easy, reproducible, and verifiable. Although Eubanks and coworkers[10] suggest that some of the errors assessed by the scoring system might not be clinically significant, they do have implications for the technical skill of the surgeon. Such a scoring system can allow surgeons to critique their skills and, with the RATE tool, to review troublesome or difficult cases easily and efficiently. The RATE system also en-

ables errors to be time stamped for quick postoperative review and discussion by the surgery team immediately after the case, while questions and issues are still fresh in their memory. Finally, using a combination of visual, technical, and audio data, this system is adaptable for use in surgeon or team performance review, as a surgical training and education tool, and for assessing competency for surgeons, including both technical and nontechnical skills (team work, communication, situation awareness, and decision making).

Using case information validated by patient chart data and the RATE tool, this study identified considerable variation in situational awareness by participants in the operative case. This highlights potential problems in health care delivery patterns whereby procedures include team members who are unfamiliar with the details of the patient or the procedure. For instance, given the question of whether an intraoperative cholangiogram or ultrasound was indicated for the patient in a case, respondents noted "a surgical, not an anesthesia problem" or "would have to ask surgeon." This problem is complicated by the very nature of the dynamic operative environment, where shift changes and circulating roles permit students, nurses, and sometimes even residents, to be present during only portions of an operative case. The result may be that only a few members of the operating team, such as the attending surgeon, hold key information about the patient's case. Although the attending surgeon is ultimately responsible for this and other aspects of the case, empowering other team members with detailed patient or case data could improve recognition of variance from the care plan, facilitate team coordination, increase operating room efficiency, and improve patient safety. For instance, in reviewing data captured by the RATE tool, no instances of a team preprocedural briefing or postcase review were seen. These simple, brief team reviews can orient the entire team to the goals for the case and the critical information needed to achieve them. Otherwise, if members of the team do not possess this critical information, a system of cross-checking the information (eg, redundancies, fail-safe backups) and preparing for the case appropriately is impossible. Rebuilding our intraoperative systems to provide appropriate checks and balances should allow case variance and errors to decrease. The novel tool, RATE, described here, has implications in better understanding and evaluating current operating room practices, identifying areas of improvement, measuring the effectiveness of interventions, and enhancing teaching methods for residents and students. Strategies involving routine preprocedural briefings and safety checklists may also improve the safety of operative procedures and the learning that occurs during elective procedures.

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